NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

EFFECTS OF A SUSPENDED SEDIMENT LAYER ON ACOUSTIC IMAGERY

by

Michael Cornelius

June 2004

Thesis Advisor: Peter C. Chu
Second Reader: Melvin Wagstaff (NAVO)

Approved for public release; distribution is unlimited

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE		*Form Approved OMB No. 0704-0188*

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE June 2004	3. REPORT TYPE AND DATES COVERED Master's Thesis	
4. TITLE AND SUBTITLE: Effects of a Suspended Sediment Layer on Acoustic Imagery		5. FUNDING NUMBERS	
6. AUTHOR(S) Cornelius, Michael			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000		8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) NAVOCEANO Stennis Space Center, MS 39522-5001		10. SPONSORING/MONITORING AGENCY REPORT NUMBER	

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited	12b. DISTRIBUTION CODE

13. ABSTRACT (maximum 200 words)

The Navy's CASS/GRAB sonar model is used to accurately simulate a side-scan sonar image with a mine-like object present through its reverberation characteristics. The acoustic impact of a suspended sediment layer is investigated numerically using CASS/GRAB through changing the volume scattering characteristics of the lower water column. A range of critical values of volume scattering strength were discovered through repeated model simulations. An understanding of the acoustic characteristics of suspended sediment layers can aid the Navy in the detection of mines that might exist within these layers.

14. SUBJECT TERMS CASS/GRAB, Modeling and Simulation, Oceanography, Mine Warfare Nepheloid Layer, Bottom Boundary Layer			15. NUMBER OF PAGES 64
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL

THIS PAGE INTENTIONALLY LEFT BLANK

EFFECTS OF A SUSPENDED SEDIMENT LAYER ON ACOUSTIC IMAGERY

Michael Cornelius
Lieutenant, United States Navy
B.S., United States Naval Academy, 1996

Submitted in partial fulfillment of the
requirements for the degree of

**MASTER OF SCIENCE IN METEOROLOGY AND PHYSICAL
OCEANOGRAPHY**

from the

**NAVAL POSTGRADUATE SCHOOL
June 2004**

Author: Michael Cornelius

Approved by: Peter C. Chu
                    Thesis Advisor

                    Melvin D. Wagstaff (NAVO)
                    Second Reader

                    Mary Batteen
                    Chairman, Department of Oceanography

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

The Navy's CASS/GRAB sonar model is used to accurately simulate a side-scan sonar image with a mine-like object present through its reverberation characteristics. The acoustic impact of a suspended sediment layer is investigated numerically using CASS/GRAB through changing the volume scattering characteristics of the lower water column. A range of critical values of volume scattering strength were discovered through repeated model simulations. An understanding of the acoustic characteristics of suspended sediment layers can aid the Navy in the detection of mines that might exist within these layers.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

ACKNOWLEDGMENTS

THIS PAGE INTENTIONALLY LEFT BLANK

I.   INTRODUCTION

In the fifteen years since the fall of the Berlin Wall and the end of the "Cold War", United States Naval Forces are still transitioning from a large "blue water" navy to a smaller, more mobile force capable of combat in the littoral regions of the world. The looming specter of the Soviet Union has been replaced by smaller regional threats that utilize unconventional tactics to inflict damage on those they oppose.

One such tactic that was prevalent during Operation Iraqi Freedom was that of using sea mines to block waterways. Naval mines are inexpensive, easily deployed, and possess extraordinary destructive capability. Once deployed, mine fields require very little maintenance and can effectively block access to ports, deter amphibious operations, prevent humanitarian assistance and psychologically affect those assigned to patrol the waters in the vicinity of the minefield. The damage caused by naval mines to U.S. assets is well documented. The USS SAMUEL B. ROBERTS (FFG-59), USS TRIPOLI (LPH-10) and USS PRINCETON (CG-59) all struck mines and received severe damage. The costs to repair the SAMUEL B. ROBERTS and the PRINCETON totaled over $125 million, not to mention the loss of human life. This staggering figure compared to the cost of the mines that caused the damage highlights the cost effectiveness of mines. Most recently, during Operation Iraqi Freedom in March of 2003, three tugboats were stopped just south of the Iraqi port city of Umm Qasr. The vessels were acting suspiciously, and were found to be carrying 70 mines of different types. The tug boats and the barge they were towing were altered so that mines could be deployed through the hull to avoid detection. Some of the mines were moored mines that detonate on contact, and some were bottom influence mines that are detonated by a ship's magnetic or acoustic signature.

Figure 1. U.S. troops inspecting mines found aboard Iraqi tug boats.

In the reverberation limiting acoustic environment of the littoral regions of the world (water depths less than 100 meters), mine detection can prove to be quite difficult. As proximity of the mine to the bottom increases, probability of detection decreases due to complex bathymetry and diverse sediment types. Further complicating the issue are "bottom boundary layers", sometimes called "nepheloid layers" or "suspended sediment layers". These layers consist of suspended sediments that occupy the lower water column, sometimes up to 10 m., and lasting for several weeks. Their effects on acoustic detection are undeniable. Bottom boundary layers can make a mine undetectable and increase the threat to personnel and equipment. Understanding exactly what the acoustic effects of bottom boundary layers are can lead to the development of acoustic sensors that can see through to the sea floor and aid in the detection of the potential hazards that lie within.

In this thesis, the effects of a suspended bottom sediment layer on high frequency acoustic imagery is studied using the Navy's Comprehensive Acoustic Simulation System with the Gaussian Ray Bundle (CASS/GRAB). A side scan sonar image of a

mine-like object on a silty clay bottom has been obtained along with the sound velocity profile and all bathymetric data corresponding to the image.

The CASS/GRAB model is run with the appropriate input file that incorporates the sound velocity profile, bottom type and bathymetric data and the scattering characteristics of a mine-like object. The bottom synthetic reverberation field calculated using CASS/GRAB is taken as the bottom reverberation as well as the echoes from the mine-like object. The volume scattering strength is used to model the reverberation caused by the suspended sediment boundary layer. The CASS/GRAB is run repeatedly while changing the value of the volume scattering strength until the modeled mine-like object disappears, which leads to a critical value representing the occurrence of the bottom suspended sediment layer, rendering the mine-like object undetectable. The critical values of volume scattering strength are then taken as a metric of the acoustic impact of the suspended bottom sediment layer.

The remainder of the thesis is organized as follows: Chapter II discusses the effects that suspended sediment has on acoustic propagation. Chapters III and IV describe the CASS/GRAB model and the input files that are required to run the model effectively. Chapters V, VI, and VII discuss the results of this work.

THIS PAGE INTENTIONALLY LEFT BLANK

II.   WORKING HYPOTHESIS AND PROCEDURE

A.   SUSPENDED SEDIMENT AND VOLUME REVERBERATION

One version of the active sonar equation, where there is zero signal excess, is given by

$$SL - 2TL + TS = RL + DT \qquad (1)$$

where SL represents the source level of the sonar, TL represents transmission loss, TS represents target strength, RL represents reverberation level and DT is the detection threshold of the sonar. Since no ambient noise information was available, the ambient noise level is assumed to be negligible. Transmission loss is multiplied by 2 because the radiated sound has to strike the target and then return, essentially making a round trip. In the detection of an object in the water, the source level and target strength must be large enough to overcome the losses of energy to transmission loss, the interference due to the reverberation, the ability of the sonar processor to enhance the signal-to-noise ratio and the ability of the operator to recognize objects.

Transmission loss is due to spreading and attenuation, and is a result of acoustic energy traveling through water (and possibly the ocean bottom) and reflecting from the ocean bottom and surface. There are three types of reverberation; volume reverberation, sea-surface reverberation and bottom reverberation. The most important factor that determines reverberation is scattering strength. (Urick, 1983) Scattering is the reflection of emitted sound from material in the water column, ocean bottom and ocean surface. The mechanisms that cause scattering can be biological, chemical or physical. The governing equation for volume scattering is:

$$S_v = 10 \log \frac{I_{scat}}{I_{inc}} \qquad (2)$$

where S_v represents the scattering coefficient, in decibels, I_{scat} represents the scattered intensity of the sound by the unit volume, and I_{inc} represents the incident intensity of the sound. When there are particles suspended in the water column, the scattering also

depends on the size and shape of the scatterers. In this work, the particles were assumed to be spherical which yields:

$$S_v = 10\log\frac{m_v}{4\pi} \hspace{3cm} (3)$$

where S_v still represents the scattering coefficient and m_v represents the backscattering cross section of a unit volume. The sum of all scattered energy in a region is defined as the reverberation (Urick, 1983). Not only does the size and shape of scatterers affect the reverberation, but the concentration of scatterers is also very important. The more scatterers there are in a unit volume, the more scattering will occur.

Volume reverberation is a function of the physical properties of the water column including any sediment, or biological material that may be suspended there. In a suspended bottom sediment layer, large quantities of sediment remain in the water column for up to several weeks. This layer significantly affects the acoustic characteristics of the water that it is suspended in. The thicker and denser a suspended sediment layer becomes, the harder it would be for a sonar to penetrate the layer. Another possible impact of a suspended bottom sediment layer would be changes in the temperature, density or salinity of the lower water column. These quantities would in turn alter the sound velocity profile and might prevent acoustic energy from reaching a possible mine. The focus of this work is on the effects of a suspended sediment layer on the volume scattering strength component of reverberation.

B.   PROCEDURE TO SIMULATE SUSPENDED SEDIMENT LAYER

The working hypothesis of this thesis is "the acoustic impact of a suspended sediment layer can be represented by high values of volume scattering in the lower water column". Using an actual side-scan sonar image as a reference, an acoustic image can be created using CASS and the bottom can be effectively "stirred-up" to create a suspended sediment layer that did not previously exist in the image. The properties of this simulated layer can then be changed so the impact of the layer can be determined.

Figure 2 shows a representation of the procedure that was followed to recreate a side-scan sonar image using CASS. The bathymetry and sound velocity profile inputs to CASS were taken directly from the side-scan sonar image. Other inputs, including surface/bottom parameters and volume scattering were modeled to reflect real world conditions.
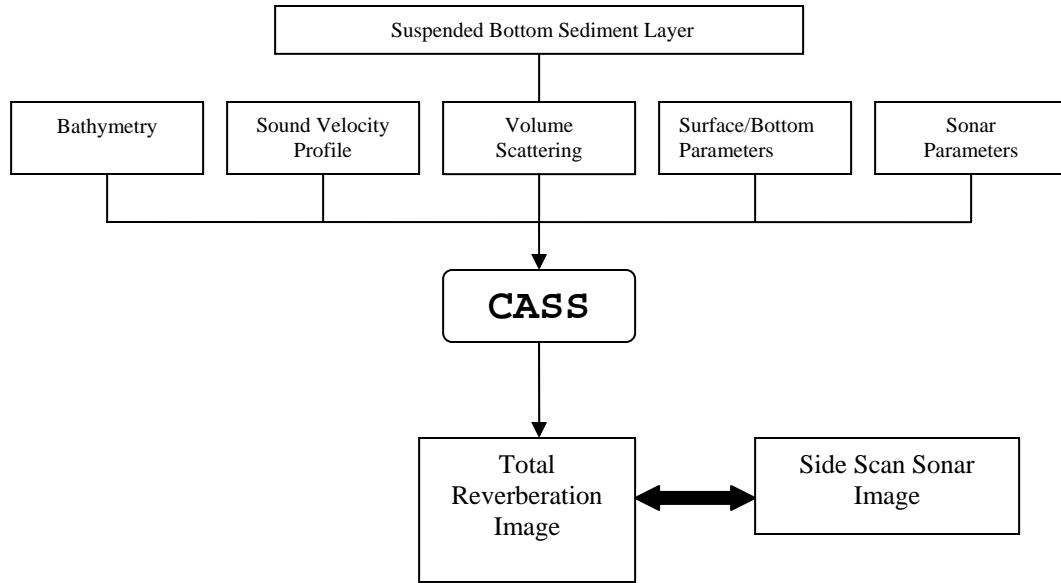
Figure 2. Steps taken to create a total reverberation image from CASS, compared to the side scan sonar image.

The total reverberation image is compared to the side-scan sonar image for accuracy before the suspended bottom sediment layer is inserted. Once a good comparison has been made, the volume scattering in the lower water column is increased to reflect the presence of the suspended sediment layer.

Figure 3 shows the decision making process that was used to determine if the chosen values of volume scattering were adequate. If the simulated mine object is still visible after increasing the volume scattering, then the simulated sediment layer is not strong enough to represent a layer that would hide a mine from a sonar. So the volume

scattering was increased further. This procedure was performed several times until the mine object was no longer visible.
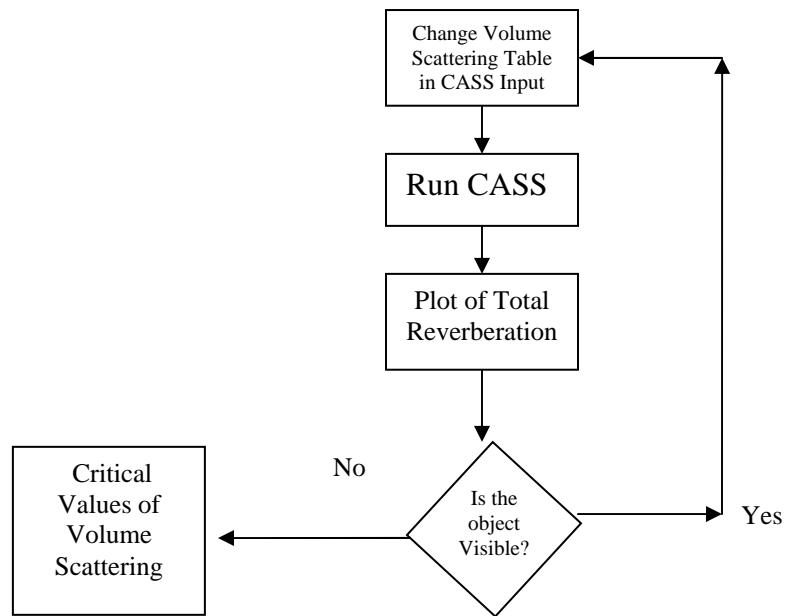
Figure 3. Procedure to determine whether object is obscured by suspended sediment layer

III. COMPREHENSIVE ACOUSTIC SIMULATION SYSTEM/ GAUSSIAN RAY ACOUSTIC BUNDLE

A. CASS MODEL FUNDAMENTALS

CASS/GRAB is one of the Navy's range-dependent propagation, reverberation, and signal excess acoustic models that can be used in both the active and passive sonar equations. The CASS model acts as the outer shell that computes range-independent monostatic and bistatic active signal excess calculations and calls on the GRAB subset for the computation of eigenrays and propagation loss (Figure 4).

**CASS
Comprehensive Acoustic
System Simulation**

Propagation Model 1: FAME

**Propagation Model 2: GRAB
Gaussian Ray Bundle**   **OAML GRAB v1.0**

Environmental Interpolations
Environmental Model Interpolations
Surface and Bottom Forward Loss
Volume Attenuation
Sound Speed Algorithms   Call GRAB

Propagation Model 3: COLOSSUS
Propagation Model 4: AMOS equations
Backscatter Models
Reverberation
Noise Models
Signal to Noise
Signal Excess
Graphic Displays
System Parameters (Beamforming)

Figure 4. CASS/GRAB Overview (From Keenan et al.2000)

In the GRAB model, travel time, source angle, target angle, and phase of the ray bundles are similar to those values for a classic ray path. GRAB, however, uses ray bundles vice a ray path. This allows the amplitude of the Gaussian ray bundle to affect all depths to some degree, whereas with classic ray paths, amplitudes are local.

B.   BATCH FILE

A template for the input file that CASS requires to compute reverberation can be found in the files that come with the program. A more specific sample of the input file that was used in this work is included in Appendix A. Once created, the input file must be called "input.dat" for CASS to read it. This presented a slight problem since the bathymetric data was in 41 different "lines". Each line represented one value of distance in the along track direction and had several values of cross track distance and depth associated with it. Hence, 41 different input files were created named "input1.dat" through "input41.dat".

The output for the CASS input file is user specified. In this case, the output file was named "revout.dat" for "reverberation output". The output file was also the same for each file and needed to be changed to something that made data retrieval more efficient.

A batch file was created that took "input1.dat" and renamed it "input.dat". Then CASS was run on "input.dat". The output file "revout.dat" was changed to "output1.dat". This batch file continued to run each file until all 41 input files have a corresponding output file. This batch file was useful because it allowed for multiple runs of CASS with varying input files in a relatively short amount of time.

IV. INPUT PARAMETERS

A. ENVIRONMENTAL PARAMETERS

The environmental parameters for the CASS input file consisted primarily of data taken at the time of the side-scan sonar image. This image shows an object that, for the purposes of this work, represents a "mine-like" object. The object is assumed to be hollow steel and sits at 30 m above the lower boundary of the image and 27 meters to the left of the right boundary of the image. The extent of the image is approximately 60 meters in the y-direction and 50 meters in the x-direction. The following sections will address each part of the environmental parameters one at a time.

1. Bottom Depth Table

The values for the bottom depth were measured at the time the image was taken. After interpolating between adjacent values to improve the resolution, values were directly entered into the table. Values of depth ranged from 95 meters to 77 meters. A plot of bathymetry contours is included later in this work.

2. Sound Speed Table

The values for the sound velocity profile were also measured at the time of the image. Figure 5 shows a plot of the sound velocity vs. depth.
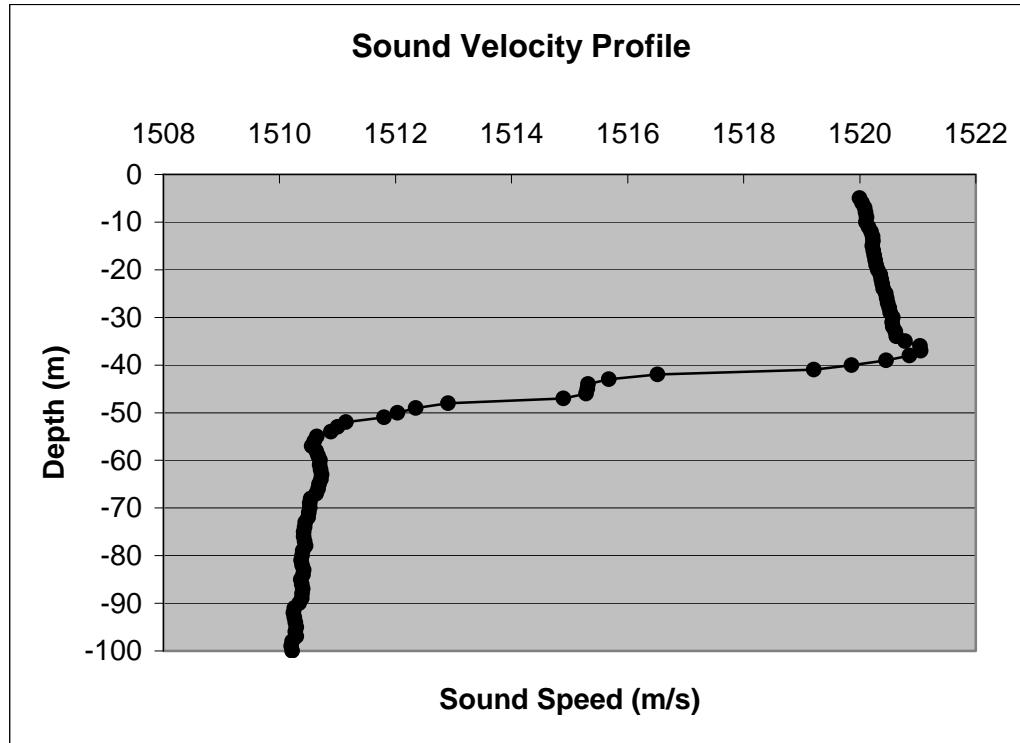
Figure 5. Sound Velocity Profile for region above "mine-like" object.

3. Bottom Parameters

Appendix B shows that the grain size index for a silty clay bottom is 8. APL/UW was the built-in model that was used to model bottom scattering. Bottom reflection effects were modeled using the Rayleigh scattering model.

4. Surface Parameters

Wind speed at the time the image was created was not recorded, so a nominal wind speed of 1 m/s was reasonable as no indication of significant winds were evidenced in the side scan image. APL/UW was the built in model that was chosen to model surface reflection and the surface scattering.

5. Volume Scattering Strength

For this work, the best way to model volume scattering strength was by a table that was directly entered into the input file. The water column was assumed to be

relatively clear above 77 meters, with an initial suspended sediment layer characterized by a slightly stronger scattering strength below 78 meters.

VOLUME SCATTERING STRENGTH TABLE

M	DB/M
0.00	-95.00
77.00	-95.00
78.00	-65.00
95.00	-65.00

Table 1. Scattering strength table for CASS input file

6.   Volume Attenuation

Out of all the models available in CASS, Francois-Garrison was the model chosen for volume attenuation. This is due to the accuracy that this model handles at higher frequencies.

B.   SONAR PARAMETERS

The sonar parameters for this work were entered to reflect that of a high frequency side scan sonar at 100 kHz. The source level was 240 dB. The sonar was towed at a depth of 30.4 meters below the surface and had a pulse length of 0.001 seconds.

C.   MODEL PARAMETERS

The time increment for modeling should not exceed one half of the pulse length to achieve proper resolution of each time step. Since the total distance traveled from the sonar to the end of the image is approximately 50m, the total reverberation time is only 0.12 seconds. The maximum number of bottom and surface reflections modeled was set at 30 to allow for some interference by reflected eigenrays.

THIS PAGE INTENTIONALLY LEFT BLANK

V. CASS REPRESENTATION OF SONAR IMAGE

The first task that was to be accomplished was to represent the side-scan sonar image (Figure 6) through reverberation output from CASS.
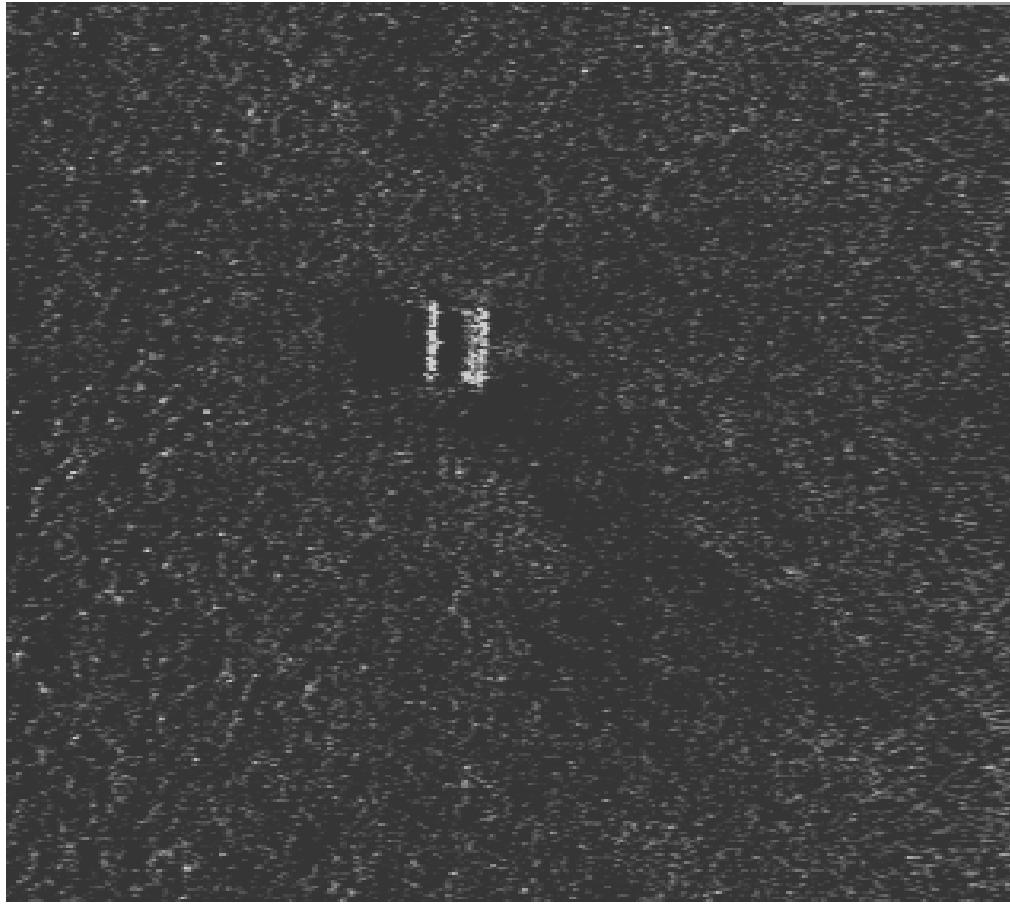
Figure 6. Klein 5000 image of "mine-like" object on silty clay bottom.

Using the input quantities from the previous section, the batch file, and a Matlab© m-file that searches through the output file and extracts the total reverberation data (Appendix C.), the following image was created that does not include the mine-like object:

15
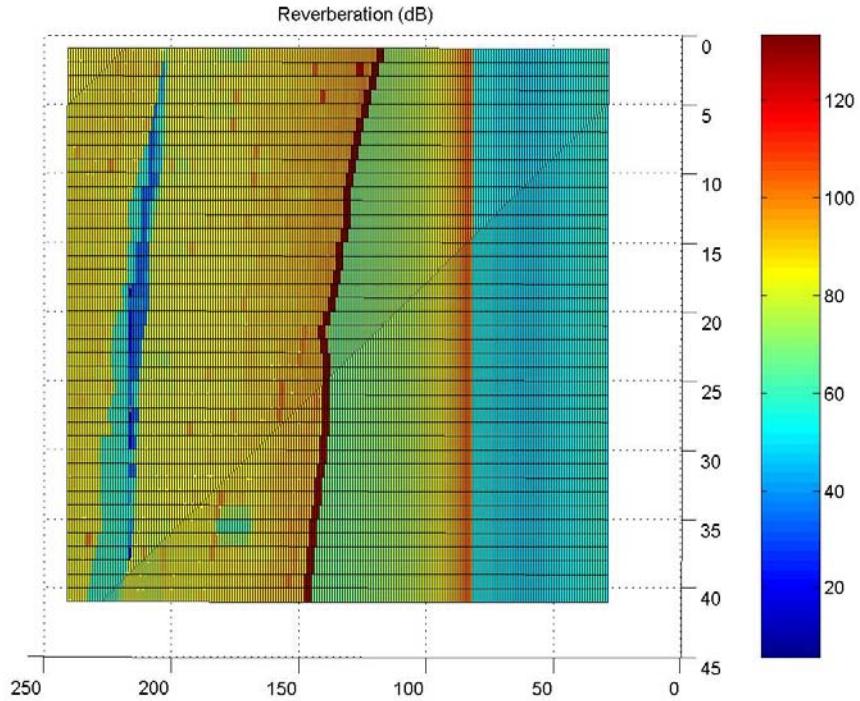
Figure 7. Reverberation plot of bottom without mine object inserted. X-axis is cross track indices represented by time and Y-axis is along track indices represented by distance.

The above plot shows that after the sound leaves the sonar, there is a brief time when no return has been received. The first blue shading is the return from volume reverberation. The first red line and the yellow field that follows is the return from the surface reverberation. The second red line is the initial return from the bottom (not unlike a fathometer). The final feature of note is the blue "trench" that appears near the far edge of the plot. This is because the sonar was located at a depth of 30.4 meters which was just above the thermocline. (Figure 5)

16

Now that there is an accurate depiction of the bottom, the next step is to insert the "mine-like" object. This is done in two steps. First, the bathymetry must be changed to reflect a mine that protrudes above the bottom. The water depth in the vicinity of the object is 87 meters. The size of the object in the image is 5 meters long, 3 meters wide and 2 meters high. Therefore, the depth in the vicinity of the mine will change to 85 meters. The width and length of the object will be exaggerated slightly to ensure that the object is hit with as many eigenrays as possible. (Figures 8 and 9)
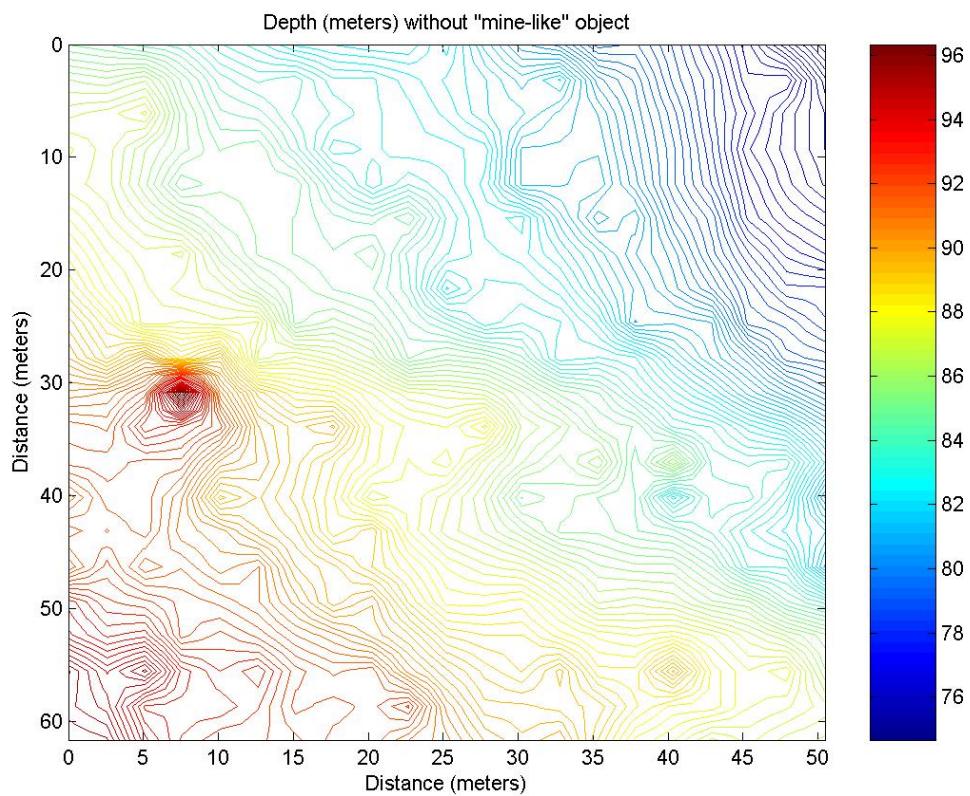
FIGURE 8. Bathymetry plot without mine object.
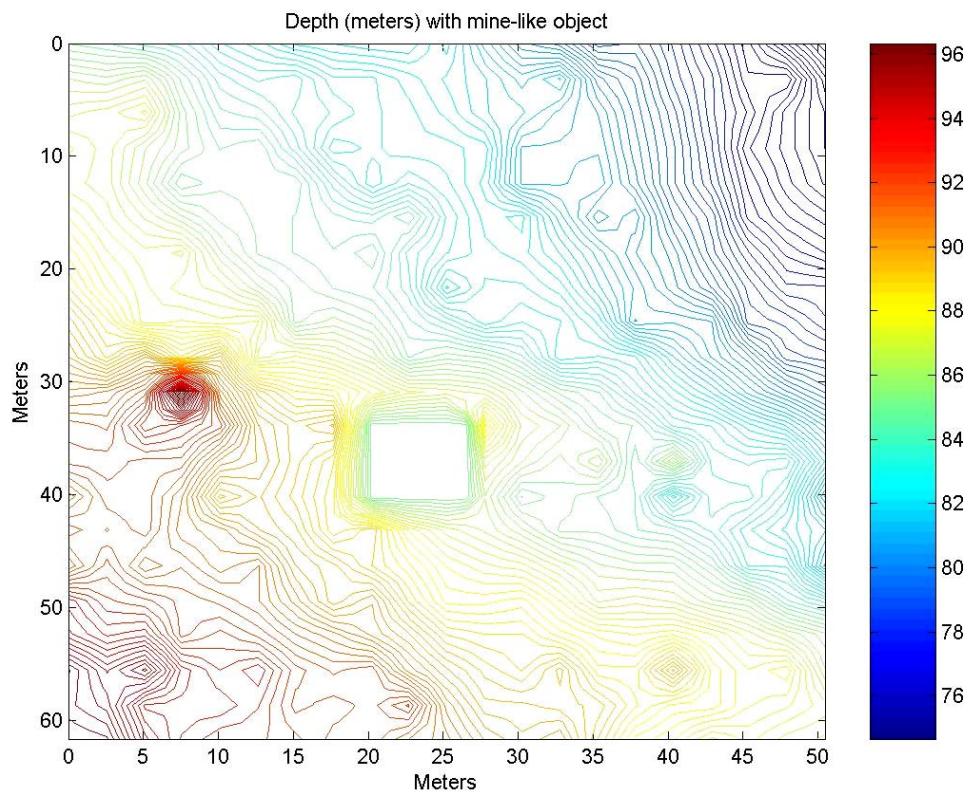
FIGURE 9. Bathymetry plot with mine object.

The second step to entering the synthetic "mine-like" object is to change the bottom parameters to reflect hollow steel instead of silty clay. This is done by means of inserting a bottom scattering strength table. (Table 1) This shows for all grazing angles, the scattering strength of the object is -1.13 dB/m^3. With no object inserted into the

bathymetry, there was only one bottom parameter for the input file. To insert an object in the horizontal, there must be three "environments". The first environment is the same as in the CASS run without the object. Files "output1" through "output17" cover this regime. The second "environment" is from files "output17" thorough "output22". This corresponds to an object that is roughly 8 meters long in the y-direction. In the x-direction, the altered bottom scattering values occupy values from 27.8 meters to 32.8 meters, producing an image that is 5 meters wide. The original object was 5 meters long by 3 meters wide. This simulated image is slightly larger, but still representative of the original.

Now, CASS is run again with the altered files. The following image is the product of this attempt:
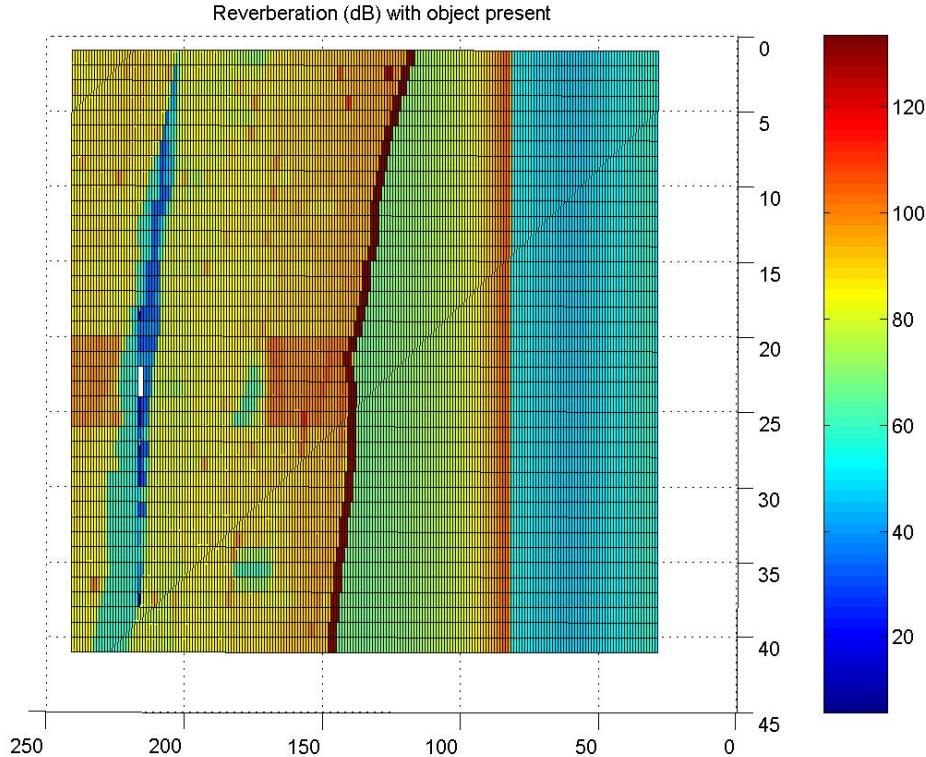
FIGURE 10. Reverberation plot of bottom with mine object inserted. X-axis is cross track indices represented by time and Y-axis is along track indices represented by distance

19

Clearly, the object is visible in the reverberation imagery. It is located at x-cooordinate 150, y-coordinate 23. All of features that were in the image without the mine are still present, but now the object itself and even an echo from the object are visible. The echo is the orange shaded area located near the left edge of Figure 10. The value of this image is that now there exists a synthetic replica of a real image that inputs that can be changed to examine the effects of various parameters.

VI.   ACOUSTIC IMPACT OF SUSPENDED SEDIMENT LAYER

As shown in the input parameters section, the volume scattering table showed a slightly elevated scattering value for the depths below 78 meters (Table 1). This elevation was part of a typical volume scattering profile. Sediment in the water column would increase the volume scattering and ultimately the volume reverberation. Since the simulated side-scan sonar image with an object inserted has inputs that can be changed, a critical value can be determined as to how much volume scattering in a simulated suspended bottom sediment layer will render the "mine-like" object undetectable. Volume attenuation and changes in the sound velocity profile will also have an effect, but they are not addressed in this work.

Starting with the input files that had the object in place, the initial value of -65 dB/m^3 was changed to -60 dB/m^3. After plotting the output, little change was noted. For the next attempt, the volume scattering was changed to -50 dB/m^3. Changes to the plot began to appear. The reverberation values around the object, in the vicinity of where the bottom reverberation appeared before, were increasing. This was significant progress, but the object was still visible. Several more attempts were made until at -30 dB/m^3, the object was almost gone. (Figure 11)
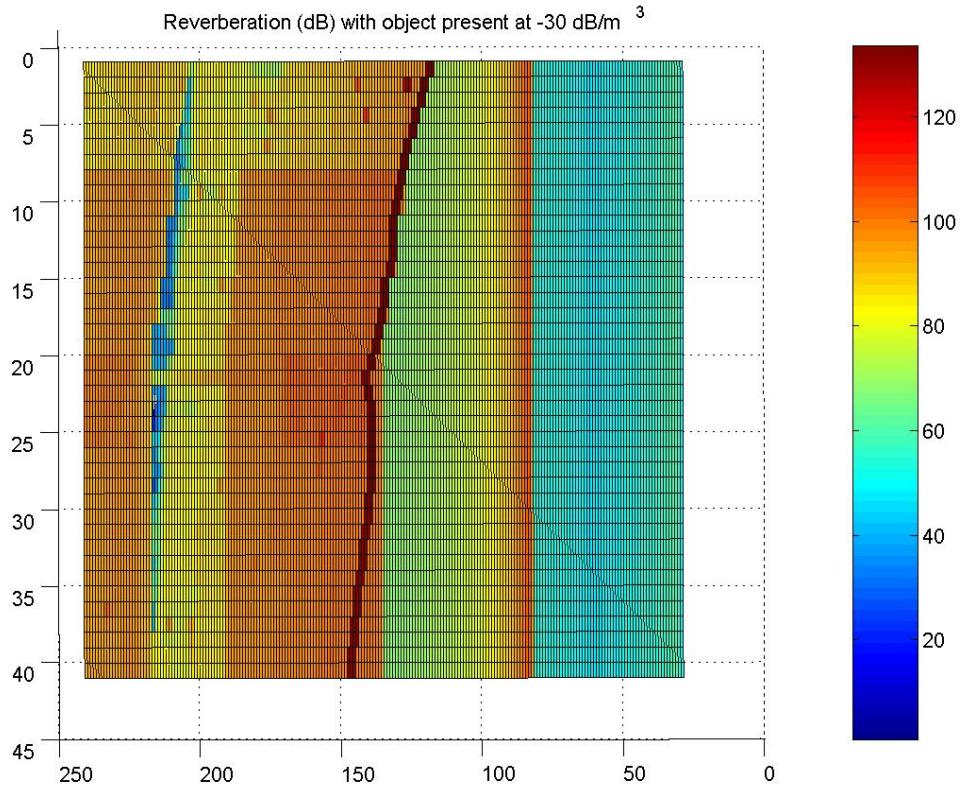
FIGURE 11. Reverberation plot of bottom with mine object inserted. X-axis is cross track indices represented by time and Y-axis is along track indices represented by distance with mine object inserted and suspended sediment layer with -30 dB/m^3
    volume scattering strength.

The object is still visible in Figure 11, but it is beginning to approach that threshold where mine detection equipment might not be able to distinguish the object from the surrounding bathymetry. Still, the goal of the experiment was to find the values of volume scattering that rendered the object undetectable. Next, volume scattering values were changed and 1 dB/m^3 intervals until finally at -22 dB/m^3, the object was completely obscured by the suspended sediment layer. (Figure 12)
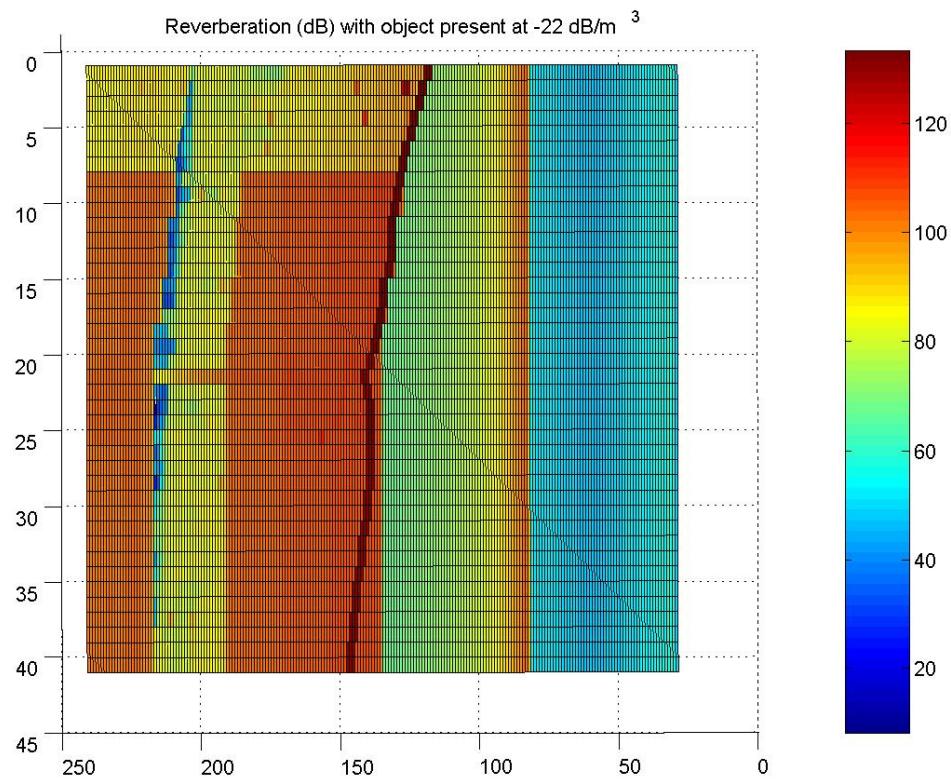
FIGURE 12. Reverberation plot of bottom with mine object inserted. X-axis is cross track indices represented by time and Y-axis is along track indices represented by distance with mine object inserted and suspended sediment layer with -22 dB/m^3 volume scattering strength

THIS PAGE INTENTIONALLY LEFT BLANK

VII. CONCLUSIONS

It has been shown that the CASS/GRAB model can be used to create a side scan sonar image by mapping the modeled reverberation and that a synthetic mine-like object can be inserted into the input file to reflect a real object. Also, for this particular instance, volume scattering values of -30 dB/m^3 to -22 dB/m^3 render the object acoustically undetectable. These values are specific to this case only and do not represent universal values. The results of this study must also be tempered with the knowledge that changes in volume attenuation and sound speed, corresponding to the change in volume scattering, were not included.

This research was valuable because it provides a product that can model the effects of a suspended sediment layer on side scan sonar imagery. Given the appropriate inputs, this product can provide results for a tactically significant issue for the mine warfare community. While the development of this product is significant, several shortfalls remain. First, the process by which the environment and the object are modeled is cumbersome. Second, the appropriate volume attenuation and sound speed must also be used with into this product. Follow-on efforts should provide solutions to the two issues listed above. Equally (or more important) is a thorough study of the relationship between the suspended sediment layer density and type (e.g., sand, silt or clay), particle density in the layer, associated volume scattering and attenuation, and changes in the sound speed profile.

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX A.   CASS/GRAB MODEL INPUT CARD FOR IMAGE WITHOUT MINE-LIKE OBJECT OR SUSPENDED SEDIMENT LAYER

```
-----------------------------

Direct Output

-----------------------------


OUTPUT FILE = REVOUT
RESET OUTPUT DEVICE


VERTICAL ANGLE MINIMUM = 0 DEG
VERTICAL ANGLE MAXIMUM = 90 DEG
VERTICAL ANGLE INCREMENT = 1 DEG



-----------------------------

Frequency

-----------------------------



FREQUENCY MINIMUM =  100000.00 HZ
FREQUENCY MAXIMUM =  100000.00 HZ
BANDWIDTH TABLE =      1.00 HZ



-----------------------------

BATHYMETRY

-----------------------------


BOTTOM DEPTH TABLE
M       M       M
0       0       84.94

1.284   0       85.5

2.568   0       86.06

3.852   0       86.34
```

5.136	0	86.62
6.345	0	86.905
7.554	0	87.19
8.838	0	87.095
10.122	0	87
11.406	0	87.28
12.691	0	87.56
13.899	0	87.845
15.105	0	88.13
16.392	0	88.41
17.676	0	88.69
18.960	0	89.065
20.245	0	89.44
21.453	0	89.72
22.662	0	90
23.946	0	90.47
25.230	0	90.94
26.515	0	91.41
27.799	0	91.88
29.008	0	91.97
30.216	0	92.06
31.500	0	91.5
32.785	0	90.94
34.069	0	91.41
35.353	0	91.88
36.562	0	91.505
37.770	0	91.13
39.055	0	92.16
40.339	0	93.19
41.623	0	93.375
42.907	0	93.56
44.116	0	94.31

45.325   0   95.06

46.609   0   94.97

47.893   0   94.88

49.177   0   95.065

50.461   0   95.25

EOT

Sound speed Table

ENVIRONMENT X COORDINATE =   0.0 M

ENVIRONMENT Y COORDINATE =   0.0 M

SOUND SPEED TABLE

M   M/S

  0.00   1519.9981

  5.00   1519.9981

  6.00   1520.0421

  7.00   1520.0862

  8.00   1520.1026

  9.00   1520.1190

 10.00   1520.1076

 11.00   1520.1517

 12.00   1520.1958

 13.00   1520.2233

 14.00   1520.2285

 15.00   1520.2172

 16.00   1520.2336

 17.00   1520.2500

 18.00   1520.2664

 19.00   1520.2827

 20.00   1520.3103

21.00 1520.3543

22.00 1520.3707

23.00 1520.3871

24.00 1520.4035

25.00 1520.4475

26.00 1520.4639

27.00 1520.4803

28.00 1520.5078

29.00 1520.5242

30.00 1520.5683

31.00 1520.5570

32.00 1520.5734

33.00 1520.6174

34.00 1520.6338

35.00 1520.7830

36.00 1521.0372

37.00 1521.0483

38.00 1520.8550

39.00 1520.4563

40.00 1519.8601

41.00 1519.2093

42.00 1516.5164

43.00 1515.6759

44.00 1515.3182

45.00 1515.3036

46.00 1515.2825

47.00 1514.8935

48.00 1512.9059

49.00 1512.3495

50.00 1512.0346

51.00 1511.8022

52.00 1511.1448

53.00	1511.0015
54.00	1510.8884
55.00	1510.6417
56.00	1510.5972
57.00	1510.5563
58.00	1510.6303
59.00	1510.6662
60.00	1510.6980
61.00	1510.6953
62.00	1510.7117
63.00	1510.7281
64.00	1510.7139
65.00	1510.6805
66.00	1510.6662
67.00	1510.6327
68.00	1510.5377
69.00	1510.5234
70.00	1510.5206
71.00	1510.5063
72.00	1510.4919
73.00	1510.4467
74.00	1510.4324
75.00	1510.4180
76.00	1510.4151
77.00	1510.4316
78.00	1510.4480
79.00	1510.4027
80.00	1510.3883
81.00	1510.3739
82.00	1510.3903
83.00	1510.4183
84.00	1510.4039

85.00   1510.3701

86.00   1510.3865

87.00   1510.4029

88.00   1510.3885

89.00   1510.3856

90.00   1510.3402

91.00   1510.2561

92.00   1510.2416

93.00   1510.2580

94.00   1510.2744

95.00   1510.2909

96.00   1510.2763

97.00   1510.2928

98.00   1510.2163

99.00   1510.2017

100.00   1510.2182

101.00   1510.2036

102.00   1510.1890

103.00   1510.2054

104.00   1510.1599

105.00   1509.9590

106.00   1509.7888

107.00   1509.6496

108.00   1509.6348

109.00   1509.5577

110.00   1509.3868

111.00   1509.1334

112.00   1508.8560

113.00   1508.4836

114.00   1508.3856

115.00   1508.2643

116.00   1507.8065

```
117.00   1507.4740
118.00   1507.3517
119.00   1507.1251
120.00   1506.4675
121.00   1505.7128
122.00   1504.5219
123.00   1498.3821
124.00   1490.8919
125.00   1485.0349
126.00   1482.3583
127.00   1480.0970
128.00   1478.3381
EOT


-----------------------------
Surface Reflection Coefficient
-----------------------------


WIND SPEED =   2.00 KNOTS
SURFACE REFLECTION COEFFICIENT MODEL = APL/UW
FUNCTION SYMBOL = SRF_RFL
FUNCTION UNIT = DB
PRINT FUNCTION VS VERTICAL ANGLE


-----------------------------
Volume Attenuation
-----------------------------


VOLUME ATTENUATION MODEL = FRANCOIS
FUNCTION SYMBOL = VLM_ATN
FUNCTION UNIT = DB
PRINT FUNCTION VS VERTICAL ANGLE
```

  Surface Scattering

SURFACE SCATTERING STRENGTH MODEL = APL/UW

FUNCTION SYMBOL = SRF_STR

FUNCTION UNIT = DB

PRINT FUNCTION VS VERTICAL ANGLE

  Volume Scattering

VOLUME SCATTERING STRENGTH TABLE

M   DB//M

   0.00   -95.00

  77.00   -95.00

  78.00   -65.00

  95.00   -65.00

EOT

  Bottom Parameters

BOTTOM SEDIMENT GRAIN SIZE INDEX = 8

BOTTOM SCATTERING STRENGTH MODEL = APL/UW

FUNCTION SYMBOL = BTM_RFL

FUNCTION UNIT = DB

PRINT FUNCTION VS VERTICAL ANGLE

BOTTOM REFLECTION COEFFICIENT MODEL = RAYLEIGH

FUNCTION SYMBOL = BTM_STR

FUNCTION UNIT = DB

PRINT FUNCTION VS VERTICAL ANGLE


```
 ------------------------------

  Source parameters

 ------------------------------
```


SOURCE LEVEL TABLE = 240.00 DB

PULSE LENGTH = 0.001 S

TRANSMITTER DEPTH = 30.4 M

SOURCE DEPTH =   30.4 M


```
 ------------------------------

  Transmitter Beam Pattern

 ------------------------------
```


TRUE TRANSMITTER BEARING = 0 DEG

TRUE TRANSMITTER HEADING = 0 DEG

TRANSMITTER HORIZONTAL BEAMWIDTH MODEL = TABLE

TRANSMITTER HORIZONTAL BEAMWIDTH TABLE

KHZ   DEG

 100.00   .15

EOT

TRANSMITTER BEAM PATTERN MODEL = TABLE

TRANSMITTER BEAM PATTERN TABLE

DEG   DB

   -90.0 -900.00

   -86.0 -900.00

   -85.0   -20.00

   -28.0   -20.00

   -12.0   0.00

```
    4.0    0.00
   20.0     0.00
   36.0   -20.00
   90.0   -20.00
EOT


   ------------------------------

   Receiver Beam Pattern

   ------------------------------


BEARING ANGLE MINIMUM = 0 DEG
BEARING ANGLE MAXIMUM = 0 DEG
BEARING ANGLE INCREMENT = 1.0 DEG
RECEIVER HORIZONTAL BEAMWIDTH MODEL = TABLE
RECEIVER HORIZONTAL BEAMWIDTH TABLE
KHZ      DEG
  100.00    .15
EOT
RECEIVER BEAM PATTERN MODEL = TABLE
RECEIVER BEAM PATTERN TABLE
DEG      DB
   -90.0  -900.00
   -82.0  -900.00
   -81.0   -20.00
    0.0   -20.00
    1.0     0.00
   15.0     0.00
   16.0   -20.00
   90.0   -20.00
EOT


   ------------------------------
```

Model and Run Parameters

EIGENRAY MODEL = GRAB

MAXIMUM BOTTOM REFLECTIONS = 30

MAXIMUM SURFACE REFLECTIONS = 30

TIME MINIMUM =   0.0 S

TIME MAXIMUM =   .12 S

TIME INCREMENT =   0.0005 S

RANGE MINIMUM =   0.0 M

RANGE MAXIMUM =   50.0 M

RANGE INCREMENT =   0.375 M

VERTICAL ANGLE MINIMUM   = -89 DEG

VERTICAL ANGLE MAXIMUM   = 89 DEG

VERTICAL ANGLE INCREMENT =   .1 DEG

ACTIVE MODE = MONOSTATIC

----

bottom depth eigenray section

TARGET DEPTH = BOTTOM

EIGENRAY FILE = EIGBTM

EIGENRAY ADDITION = RANDOM

COMPUTE EIGENRAYS

----

surface depth eigenray section

TARGET DEPTH = SURFACE

EIGENRAY FILE = EIGSRF

EIGENRAY ADDITION = RANDOM

COMPUTE EIGENRAYS

  Target depth eigenray section

TARGET DEPTH = 20.0 M

SCATTERING LAYER THICKNESS = 40.0 M

EIGENRAY FILE = EIG001

EIGENRAY ADDITION = RANDOM

COMPUTE EIGENRAYS

TARGET DEPTH = 60.0 M

SCATTERING LAYER THICKNESS = 40.0 M

EIGENRAY FILE = EIG002

EIGENRAY ADDITION = RANDOM

COMPUTE EIGENRAYS

TARGET DEPTH = 81 M

SCATTERING LAYER THICKNESS = 15.0 M

EIGENRAY FILE = EIG003

EIGENRAY ADDITION = RANDOM

COMPUTE EIGENRAYS

  Compute Reverberation

FATHOMETER RETURN MODEL = NB

REVERBERATION MODEL = NB

RESET REVERBERATION

COMPUTE FATHOMETER RETURNS

EIGENRAY FILE = EIGSRF

COMPUTE SURFACE REVERBERATION

EIGENRAY FILE = EIGBTM

COMPUTE BOTTOM REVERBERATION

EIGENRAY FILE = EIG001

COMPUTE VOLUME REVERBERATION

EIGENRAY FILE = EIG002

COMPUTE VOLUME REVERBERATION

EIGENRAY FILE = EIG003

COMPUTE VOLUME REVERBERATION

PRINT REVERBERATION VS TIME

END

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX B. BOTTOM TYPE GEO-ACOUSTIC PROPERTIES FROM NAVO (1999)

Bottom Composition	Grain Size	Long Name	Density	Sound Speed Ratio	Wave Number Ratio	Volume Parameter ***	Spectral Exponent ***	Spectral Parameter ***
BOULDER	-9.0	ROUGH ROCK	2.500	2.5000	0.01374	0.0020	3.25	0.206930
ROCK	-7.0	ROCK	2.500	2.5000	0.01374	0.0020	3.25	0.018620
	-3.0	COBBLE	2.500	1.8000	0.01374	0.0020	3.25	0.016000
GRAVEL	-3.0	GRAVEL	2.500	1.8000	0.01374	0.0020	3.25	0.016000
	-3.0	PEBBLE	2.500	1.8000	0.01374	0.0020	3.25	0.016000
	-1.0	SANDY GRAVEL	2.492	1.3370	0.01705	0.0020	3.25	0.012937
	-0.5	VERY COARSE SAND	2.401	1.3067	0.01667	0.0020	3.25	0.010573
	0.0	MUDDY SANDY GRAVEL	2.314	1.2778	0.01630	0.0020	3.25	0.008602
	0.5	COARSE SAND	2.231	1.2503	0.01638	0.0020	3.25	0.006957
	0.5	GRAVELLY SAND	2.231	1.2503	0.01638	0.0020	3.25	0.006957
	1.0	GRAVELLY MUDDY SAND	2.151	1.2241	0.01645	0.0020	3.25	0.005587
SAND	1.5	SAND	1.845	1.1782	0.01624	0.0020	3.25	0.004446
	1.5	MEDIUM SAND	1.845	1.1782	0.01624	0.0020	3.25	0.004446
	2.0	MUDDY GRAVEL	1.615	1.1396	0.01610	0.0020	3.25	0.003498
	2.5	FINE SAND	1.451	1.1073	0.01602	0.0020	3.25	0.002715
	2.5	SILTY SAND	1.451	1.1073	0.01602	0.0020	3.25	0.002715
	3.0	MUDDY SAND	1.339	1.0800	0.01728	0.0020	3.25	0.002070
	3.5	VERY FINE SAND	1.268	1.0568	0.01875	0.0020	3.25	0.001544
	4.0	CLAYEY SAND	1.224	1.0364	0.02019	0.0020	3.25	0.001119
	4.5	COARSE SILT	1.195	1.0179	0.02158	0.0020	3.25	0.000781
	5.0	SANDY SILT	1.169	0.9999	0.01261	0.0020	3.25	0.000518
	5.5	MEDIUM SILT	1.149	0.9885	0.00676	0.0010	3.25	0.000518
	5.5	SAND-SILT-CLAY	1.149	0.9885	0.00676	0.0010	3.25	0.000518
SILT	6.0	SILT	1.149	0.9873	0.00386	0.0010	3.25	0.000518
	6.0	SANDY MUD	1.149	0.9873	0.00386	0.0010	3.25	0.000518
	6.5	FINE SILT	1.148	0.9861	0.00306	0.0010	3.25	0.000518
	6.5	CLAYEY SILT	1.148	0.9861	0.00306	0.0010	3.25	0.000518
MUD	7.0	SANDY CLAY	1.147	0.9849	0.00242	0.0010	3.25	0.000518
	7.5	VERY FINE SILT	1.147	0.9837	0.00194	0.0010	3.25	0.000518
	8.0	SILTY CLAY	1.146	0.9824	0.00163	0.0010	3.25	0.000518
CLAY	9.0	CLAY	1.145	0.9800	0.00148	0.0010	3.25	0.000518
	10.0		1.145	0.9800	0.00148	0.0010	3.25	0.000518

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX C. MATLAB© M-FILE TO RETRIEVE REVERBERATION INFORMATION

```
% file = PlotCASSReverb_all.m
%
clear
deflow = 0.0;                % min value is Zero
for kk = 1:41
  fname = ['output' int2str(kk) '.DAT']
  fid = fopen(fname,'r');
  %
  % Acquire reverberation data.
  %
  string = fgetl(fid);
  boogie = 1;
  while boogie == 1
    string = fgetl(fid);
    if length(string) > 25
      if string(24:25) == 'NB'
        boogie = 0;
      end
    end
  end
  string = fgetl(fid);
  string = fgetl(fid);
  string = fgetl(fid);
  string = fgetl(fid);
  for j = 1:241
    string = fgetl(fid);
    A(1,j) = str2num(string(1:12));           % Col 1 -- Time
    A(2,j) = max(deflow,str2num(string(61:72)));      % Col 6
  end
```

```matlab
    fclose(fid);

    Atime = A(1,:);          % Min time is 1st value in row (Left)

    index = find(A(2,:) == 0);      %  Find zeros

    A(2,index) = NaN;               % replace zero with NaN

    %Atotal(kk,:)   =   A(2,:);                    %Left-to-right  row  vector  with
                                          A1 in Row 1 (top of matrix)

    Atotal(42-kk,:) = A(2,:);       %Left-to-right row vector
                      with A1 in Row 41 (bottom of
                      matrix)

End
```

LIST OF REFERENCES

Keenan, R.E., *An Introduction to GRAB Eigenrays and CASS Reverberation and Signal Excess.* Science Applications International Corporation, MA, 2000.

Naval Oceanographic Office Systems Integration Division, *Software Design Document for the Gaussian Ray Bundle (GRAB) Eigenray Propagation Model.* OAML-SDD-74. Stennis Space Cneter, MS, 1999.

Naval Oceanographic Office Systems Integration Division, *Software Requirements Specification for the Gaussian Ray Bungle (GRAB) Eigenray Propagation Model.* OAML-SRS-74.

Urick, R.J., *Principles of Underwater Sound,* McGraw-Hill, New York, 1983

THIS PAGE INTENTIONALLY LEFT BLANK

INITIAL DISTRIBUTION LIST

1.   Defense Technical Information Center
        Ft. Belvoir, Virginia

2.   Dudley Knox Library
        Naval Postgraduate School
        Monterey, California

3.   Dr. Mary L. Batteen
        Department of Oceanography
        Naval Postgraduate School
        Monterey, California

4.   Oceanographer of the Navy
        Naval Observatory
        Washington, D.C.

5.   Commander
        Naval Meteorological and Oceanography Command
        Stennis Space Center, MS

6.   Commanding Officer
        Naval Oceanographic Office
        Stennis Space Center, MS

7.   Chief of Naval Research
        800 North Quincy Street
        Arlington, VA

8.   Superintendent
        Division 7300 - Oceanography
        Naval Research Laboratory
        Stennis Space Center, MS

9.   Professor Peter C. Chu Code OC/CU
        Department of Oceanography
        Naval Postgraduate School
        Monterey, California

10.   Mr. Edward C. Gough Jr
        Commander
        Naval Meteorological and Oceanography Command
        Stennis Space Center, MS

11. CDR Eric Gottshall
    SPAWAR, PMW-155

12. Mr. Melvin D. Wagstaff
    Naval Oceanographic Office
    Stennis Space Center, MS

13. Dr. Edward Johnson
    Naval Oceanographic Office
    Stennis Space Center, MS

14. CDR Eric Long
    Chief of Naval Operations, N752
    Washington, D.C.

15. Mr. Mark Null
    Naval Oceanographic Office
    Stennis Space Center, MS

15. Mr. Ron Betsch
    Naval Oceanographic Office
    Stennis Space Center, MS

16. LT Michael Cornelius
    NAVLANTMETOCCEN
    Norfolk, VA